Application of Temporal and Spatial informatics in Forest Ecosystem Management - An Example of Taiwan

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【Abstract】 The focused works of ecosystem management are collecting, integrating and analyzing temporal and spatial data by 5S spatial technologies. There are remote sensing (RS), permanent sampling plots (PSP), global position system (GPS), geographical Information system (GIS) and simulation modeling system (SMS) included in the 5S spatial technologies. We have to develop the spatial information of interested area in Taiwan Island. All the value of biological factors and habitat factors were developed and integrated in 40mx40m grid-based geo-database management system (Geo-DBMS). The spatial data of biosphere in GIS are multi-scale with species, population, community, ecosystem and landscape levels. Getting the spatial information of status, function and change, we have to develop and analysis temporal-spatial data with empirical models, process models and scenario simulation.

The vegetation map, forest types map and land-use map of current status and potential, suitable maps are very important to do ecosystem assessment, planning and management. "How to integrate those bio-ecological factors distribution and forest management theme maps and attribute tables to be a compatible geoDBMS" would be a key work in ecosystem management. GIS and SQL-based DBMS are good tools in integration, hierarchical classification and ecosystem management mapping and modeling.

Potential-Vegetation map were digitized with vegetation distribution criteria of elevation, climate, topology, river system and mountain ridge from field surveyed data of sampling plots and ecologist's experience in GIS.

【Keywords】DTM, Forest inventory, Vegetation map, GIS. Remote sensing (RS), Permanent sampling plot (PSP), Multi-scale DBMS, Forest Ecosystem Management (EM), Eco-region map, Ecological site quality (ESQ), Habitat suitability index (HIS)

Introduction

5S spatial technologies

We could collect spatial data with global position system (GPS) and remote sensing (RS) of photogramnetry and satellite remote sensing, collecting temporal data with permanent sampling plot (PSP) and RS. To integrate the existing data, digital image data of RS and ground survey data in geographical information system (GIS) and SQL server, we could get the temporal and spatial DBMS (Geo-DBMS) with map layers and attribute tables. To retrieve the data from Geo-DBMS, we could develop information of status, function and change in different scales of multi-levels with temporal scale and spatial scale in multi-scale with simulation modeling system (SMS).　There are individual tree, stand and forest (population, community and landscape) in the multi-level. Sampling was applied from the population of upper level to lower level and estimation could be practiced from lower level to upper level.

Forest Ecosystem Management

The concept of forest ecosystem management (EM) is based on human beings' no-ending demand of goods and service, and scarcity of biological and ecological resource.　How to manage forest under limited knowledge and techniques？It's necessary to integrate the public, researchers and managers to adaptive manage forest.　We have to create the criteria and index of sustainable management in different scales-landscape, ecosystem, stand and individual trees etc.　We have to collect the data items were derived from the criteria and index.　Setting up the existing data or data collected by ground survey of permanent plots, remote sensing, photogramnetry, global position system（GPS）,and survey data in geographical information system（GIS）, we could do spatial analysis, non-spatial analysis and temporal analysis for information. Managerial experiments were designed under the objectives of forest management insufficiency of biology, ecological, social and economical knowledge and techniques for adaptive management.　Forest scenario models are developed for ideal forest in the future.　In the processing of managerial experiments and forest scenario models, we have to measure and evaluate the criteria and index for monitoring.　From the results of monitoring, we could develop and improve management scenario.

Geo-referenced datable

The geo-referenced database of different divisions in Taiwan were try to establish with GIS in the last 10 years. How to use the database for delineating the boundary of eco-region is not compromised in Taiwan, yet. So, we have to get the experience and skills of compromising in delineating eco-regions and developing and applying eco-region classification. To introduce the skill of eco-region classification and evaluating the availability of the geo-referenced database are other key objectives in EM. After the database evaluation, we could develop the ecological classification system for ecosystem management.

Land-use classification and forest management for forest functions are needed in forest ecosystem management. Those forest functions are productivity, biodiversity, health and carbon sequestration. We could get the productivity information from analyze the data of increment boring, stem analysis, PSP surveyed data and site factors with ecological site quality (ESQ) model. Biodiversity information could be got from the data of species abundance distribution and habitat factors with habitat suitability index (HIS) model. Health information could be got from invaded species distribution and area with forest insect/disease infection. Carbon sequestration (sink and flux) information could be got from the growing stock and increment data.

The spatial and temporal informatics was used for implementing EM and monitoring to reasonable land-use classification in spatial allocation and temporal schedule and forward the desired future condition (DFC) of forest functions in spatial allocation and temporal schedule.

Data and Methods

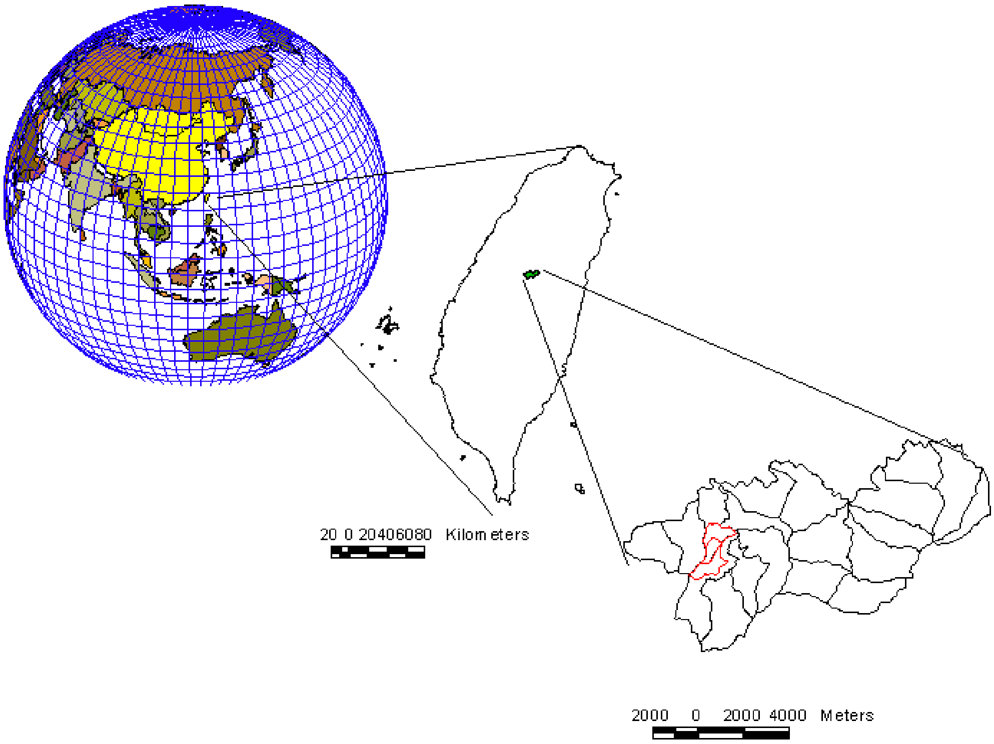


Fig 1. The location of Guandeushi LTER and the Hui-Sun Experimental Station within Taiwan,

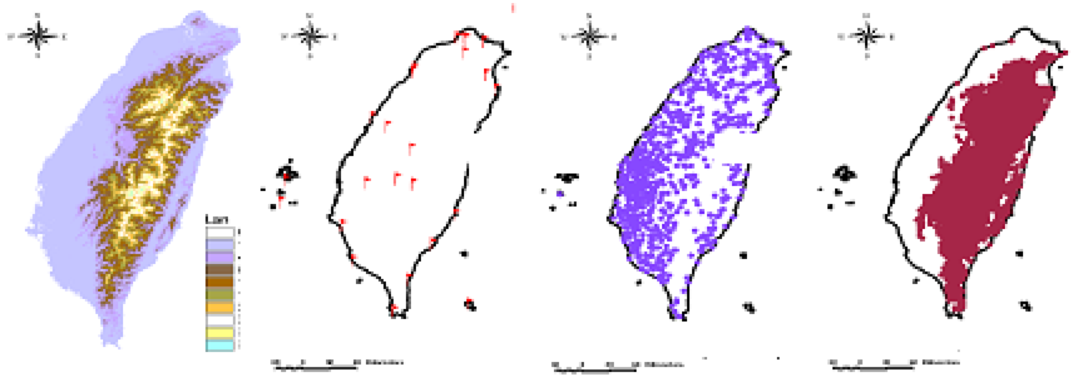
A. Taiwan

The mountainous island of Taiwan has an area of 3,598,000 hectares (ha.) and lies off the southeast coast of Mainland China to the north of the Philippines. The Central Mountain Range runs north south in the center part of the island. The island can be divided into three topographic regions (1) the plain region with 961,779 ha. (26.71% of the area), (2) hilly region (slope lands) with 980,216 ha. (27.22 %) and (3) Mountain Region with 1,659,442 ha. (46.07 %)(Dep. of Arg. and For, Taiwan Provincial Gov. 1995).

B. Hui-Sun Experiment Forest Station

The Hui-Sun Experiment Forest Station is located in the Beikangshi watershed in Nantou County in the central part of Taiwan. The station (7600 ha) contains 19 forest compartments and 4 rivers. The elevation ranges from 550 m to 2400 m. As a result of Taiwan's third forest inventory and land use survey, there are several monitoring experiments in the station, including the Son-fen Mountain Area and a 400 ha. Long-Term Ecological Research (LTER) site. This LTER site contains seed production gardens of *Schima superba* and *Calocedrus formosana*. Within the LTER site are many field studies of forest vegetation, biomass, productivity, parasitic plants, mammals, birds, insects, hydro-chemicals, nutrient cycling, and meteorology.

The environmental data were came from (a) Digital Elevation Model from a 40m*40m grid, (b) 26 climate stations (c) 818 rain stations (d) 1,791 sampling points for soil resources (Feng and Kao 2001) showed in Fig2. The 12 forest habitat variables were: elevation, slope, aspect, yearly mean temperature, mean maximum temperature (from July), mean low temperature (from January), total precipitation per year, total precipitation per winter season, total precipitation per summer season, and soil type, soil class, and effective depth. Habitat data used were collected from Taiwan raster base-map of 35,990 grids of 1km square and 32million grids of 40mX40m.



(a) (b) (c) (d)

Fig 2. Materials are (a) DEM with 40m x 40m grid (b)26 climate stations (c) 818 rain stations (d) 1,791 sampling points for soil resources.

Methods

1. GeoDBMS development : All the value of biological factors and habitat factors were developed and integrated in 40mx40m grid-based geo-database management system (Geo-DBMS).

2. Spatial Interpolation: Spatial interpolation methods were used to estimate the characteristics of population from samples. Huei-Sum Forest Experimental Station of NCHU and whole Taiwan are the study area in the study. Interpolation methods were Kriging, trend method and Thiessen polygon.

3. Forest land classification : The two primary parameters of Holdridge life zone classification model are bio-temperature and annual average precipitation. by using ArcView GIS.

4. Schnute's growth model were used to describe the growth of tree and forest in different location

$$W=[W_1^s+(W_2^s-W_1^s)\frac{1-e^{-r(t-\tau_1)}}{1-e^{-r(\tau_2-\tau_1)}}]^{1/s}$$

W_2,W_1 : The size of interested variables in T2, T1
r, s : parameter
(Schnute 1981). The Schnute's growth model is applied to the different characteristics of stand growth, stand structure of 5 kinds of planting density of Cryptomeria japonica age of in Taiwan.

Hegyi (1973) developed the formula of competition index (CI) as follows:

$$CI_j=\sum_{i=1}^{n}\left[\frac{D_i}{D_j}\times\frac{1}{L_{ij}}\right]\cdots\cdots\cdots\cdots\cdots \quad (1)$$

CI_j：Competition index of jth tree
L_{ij}： The distance between the interested jth tree and its neighbor ith tree
D_i ,D_j：The DBH of interested tee jth tree and its neighbor tree ith
n：The number of competed trees in effected circles

5. Holdridge Life Zone Classification : The two primary parameters of Holdridge life zone classification model are bio-temperature and annual average precipitation potential evapor-transpiration ratio(PET Ratio)(Holdridge ,1967).

6. Ecological Site Quality (ESQ): the ecological site quality (*ESQi*) of forest with environmental factors (climate and soil factors) in spatial modeling. Those environmental factors are light *fi* (AL), temperature responded function *fi* (TF) of climate, dry tolerance *fi* (WiF), wet *fi* (WeF) and N contents *fi* (NF) responded function of soil. Spatial interpolation method and spatial analysis were used to estimate the climate and environment factors of Taiwan in 40m x 40m grids. These factors of relative light radiation, temperature, precipitation, ground water level, potential evapor-transpiration and available N contents in soil were normalized in the scale of 0~1, except the shade intolerance tree species. The model $Qi=fi(AL)\times fi(TF)\times fi(WiF)\times fi(WeF)\times fi(NF)$, were used to evaluate site quality of forest. (Feng & Wu 2003)

7. Habitat Site Index (HSI)
The colored aero photos were scanned and corrected to be orthogonal images. Then, land cover was interpreted, and land-use, crown closure mapping and digital surface model (DSM) building with digital photogramnetry and GIS. Habitat suitability index (HSI) of warbler species and guild were evaluated for biodiversity of landscape and validated with ground-surveyed data with good results.

8. Weibull pdf：

Weibull probability density function W(a、b、c) were used to descries the distribution of ecological amplitude of habitat factors.

9. Scenario Simulation

To simulate the distribution of Holdridge life zone, where environmental changes using Holdridge life zone classification model of Taiwan as doubly increasing CO2 concentration and incrementing from 1℃, 2℃ and 4℃.

Results and Discussion

Status

4S (RS, GPS, PSP and GIS) techniques were used to data collection and storage B/W and colored aerial-photos were scanned to be 21μ digital image files. Mosaic images and maps of objective area were made in GIS base. We interpretate and digitize the boundary of different kinds of land-cover from image into land-cover maps in screen. Digital terrain model (DTM) and Digital surface model (DSM) were made from stereo-photos. The stand height and crown closures were derived from the digital aerial orthogonal photos with neighborhood spatial method. The Hui-Sun Forest Experimental Station is an example for the theme-map layers. We got the image B/W and color aerial photos from photogrametry / Remote sensing. To get the location of coordinated information of individual tree, stand (plot) and forest (land-use types and habitat observed).

To develop the forest ecosystem multi-scale database of Taiwan in biology and habitat. We suggest the multi-scale database could include individual tree, stand, community, ecosystem and landscape levels in multi-scale habitats.

1. Individual tree DBMS—to link the tree location map and attributes of individual tree (such as DBH, height, BA and V etc.).
2. Stand DBMS – to link the sample plot map with stand attribute tables which including stand composition, stand structure etc.)
3. Ecosystem DBMS- to integrate different communities with ecological attributes (such as diversity index and process)
4. Landscape geo-referenced DBMS - to pattern and process in landscape elements – matrix, corridor and patches.

To select data from upper level to lower level is sampling (or scaling down). To estimate the mean, variance or distribution of characteristic of samples to upper level population is estimation (or scaling up).

Tree location map

Feng and Lee (2000) apply GIS in making individual tree location map of permanent sampling plots（PSPs）. The attribute data of each tree were integrated with individual tree location map for tree geo-referenced database. Geo-statistical procedures were used to analyze spatial patterns of the completely mapped tree data. Analyses were used to explore the effect of distance and competition to tree growth, too. The results of spatial analysis could be applied to do thinning design. In the study, there are five 80m*50m sampling plots of Chain-fir in Hui-Sun Experimental Station were developed to be tree and stand geo-referenced database. Hegyi competition index and Schnute's growth model were used to describe the individual tree competition and potential growth of tree. The smaller the Hegyi competition index, the more less those stress. The bigger the growth potential of the tree, the longer life span will exist. The maximum of China-fir age will be 400 years old, DBH be 65 cm. So, need to do thinning for decreasing the competition stress and promoting the growth potential of the surveying tree. For there is geo-referenced database, we could do thinning design early. The scenarios of thinning design and selecting thinned tree will be easily to practice by the tree and stand geo-referenced database.

Sampling plot location map

GPS is being developed to support coordinates and altitudes on the earth‘s surface.

GIS was evolved for storing and analyzing diverse spatial data. GPS was used to collect spatial data with coordinates. The data were combined into GIS database and added the function of data input and transformation. Feng and Huang (1996) integrated GPS and GIS techniques in forest mapping. Feng and Huang (1994) applied differential GPS with laser surveyor in positioning permanent sampling plots (PSP) in forest or riparian area and forest road accurately. GIS could be used to label the coordinate data. Putting the coordinate data in GIS, we could link the spatial and attribute data of permanent plots easily. If we overlay the plots map with forest-type map and environmental factors distribution maps , we could masked the interested sampling plots location area get a lots of environmental factor for modeling and estimating.

Forest type map / Land-use map

Existing Forest Zoning

Existing forest zones could be classified with announced conditions. There are four forestland zones announced by Taiwan forest Bureau in Taiwan, which are nature reserves, land protection area, forest recreation area and timber management area (TFB, 2003) which showed in Fig 3.. The detailed area of the four forest land zones are included as follows：

(1) Nature reserves: Giving the first priority to Biodiversity conservation, then to soil and water conservation. We applied the criteria of nature reserves as follows: A. Natural forests, B. Rivers and their riverbank protected areas C. For protecting national unique natural-scenery, wildlife and historical relics D. Wildlife and habitats conservation E. For the need of natural conservation. The map of nature reserves area distribution could be zoned in Fig 5.

(2) Land protection area: Focusing on the benefits of forestland protection; and using appropriate reforestation measures and construction methods benign to ecosystem,

in order to protect forests and waters We applied the criteria of land protection area follows: A. Protection forests, reservoir watersheds, tap-water source quality protection area, inoperable area, B. Areas at elevations higher than 2500 meters or having slopes greater than 35 degrees, C. The forestlands classified into IV and V class categories in soil productivity evaluation. There are 9 catalogs of protective function forests were distributed in the area of Taiwan. The protection forest map showed in Fig.4.

(3) Forest recreation area: Coordinating with the public need of eco-tourism, being guided by forest resource, and emphasizing on environmental education. We applied the criteria of forest recreation area, such as A. The forest recreation area established according to the Forest Law, B. The recreation area established according to the National Park Law C. The sustainable development area in wildlife refuges established according to the Wildlife Conservation Law D. The recreation and service facility areas established according to the National Scenic Area project. There are 16 forest recreational areas map showed in Fig.6.

(4) Timber management area: Commercial forests aimed at reforestation, timber production, and by-product cultivation. We applied the criteria of timber management area as follows:

(5) A. Areas at elevations lower than 2500 meters or having slopes smaller than 35 degrees, B. The forestlands classified into I, II and III class categories

(6) C. Plantations, flat and deep-soil areas, D. Areas close to roads and suitable for timber operation which included 26 plantation center. (The map showed in Fig.7.)and the 36 thousands ha. of stand conversion(The map showed in Fig.8.) and are included in forest economical area.

The protected area was included reservoirs, important wildlife habitats, national parks and drinking water quality protection area. and timber production area were suggested and showed in land-use map, separately.

The forest types map of national forest in Taiwan was made from aerial photos and ground survey in the 3th Forest Inventory and Land-use Survey 1988-1995. (TFB 1995). The land-use map showed in Fig 10.

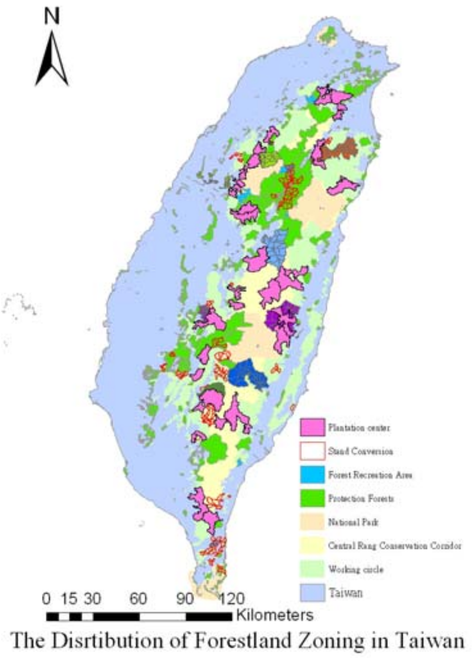


Fig 3. Four forestland zoning in Taiwan.

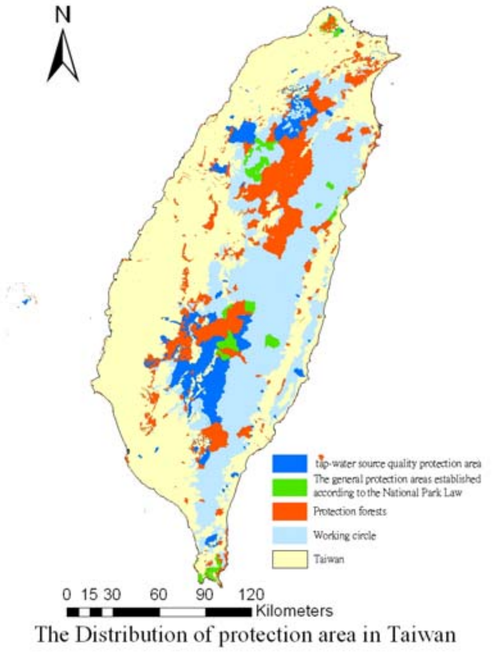


Fig 4. Protection area distribution map in Taiwan.

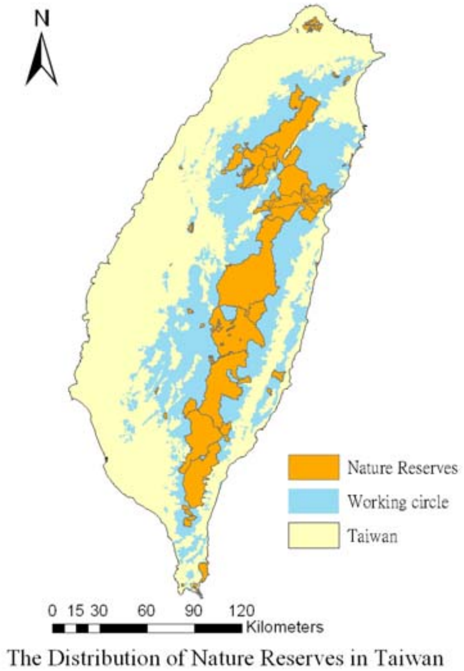


Fig 5. Natural resource range of central mountain

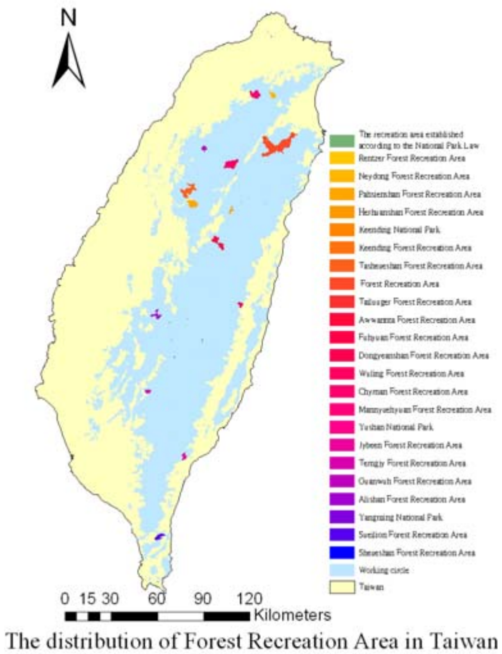


Fig6.Forest recreation area distribution in Taiwan.

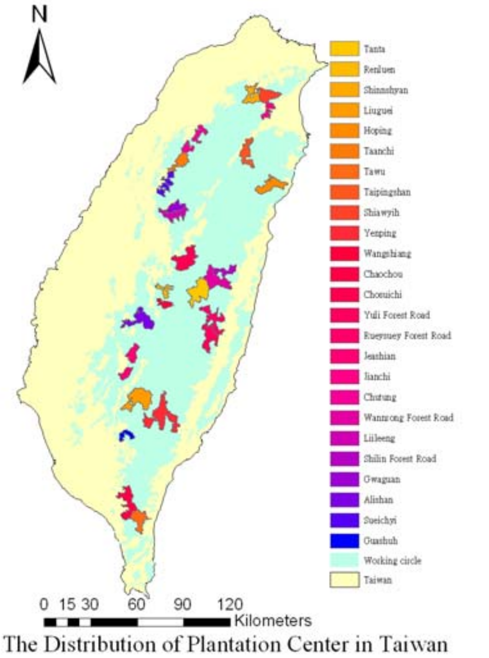


Fig7. There are 26 plantation central area

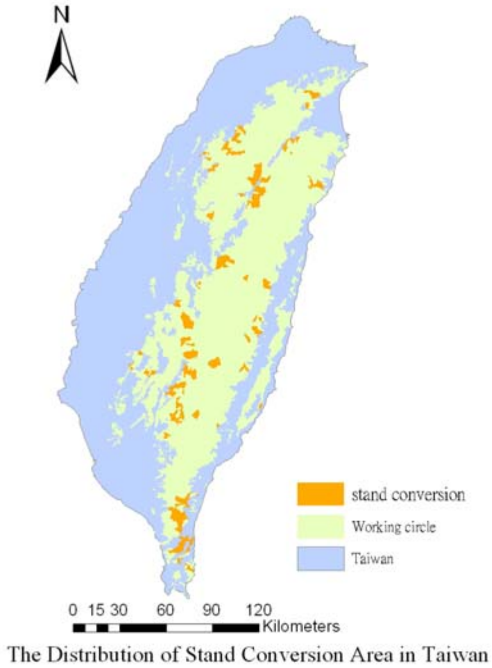


Fig. 8 Stand conversion area in Taiwan

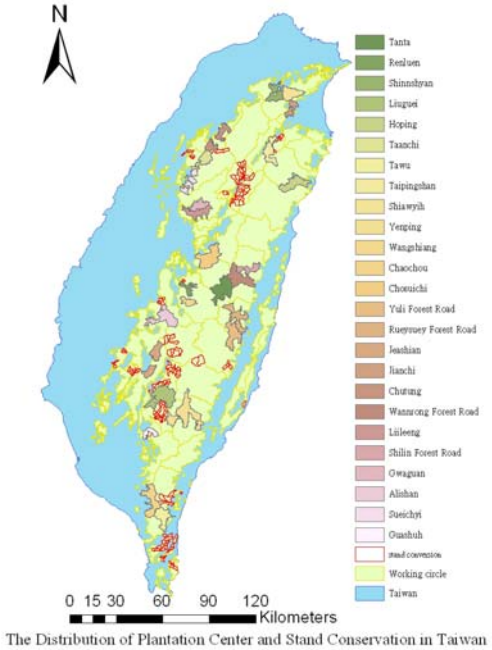


Fig 9. The timber management area of Taiwan (which overlay plantation central area map stand conversion area).

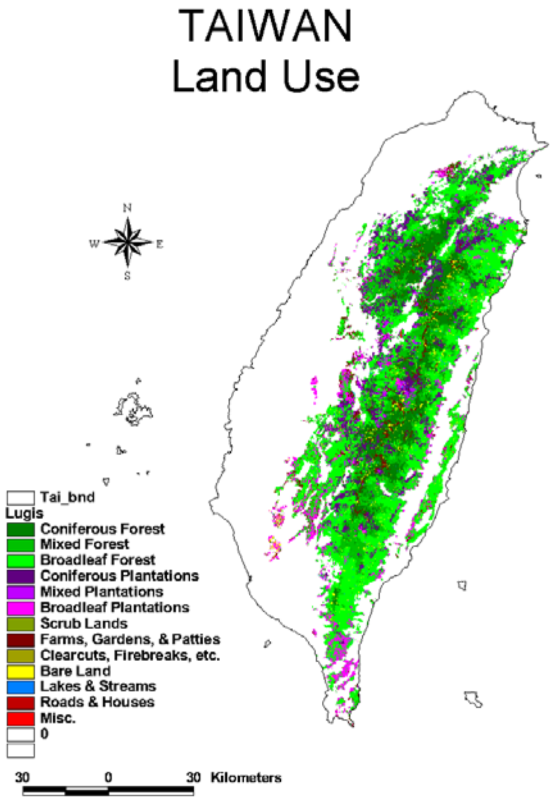


Fig 10. The forest types map of national forest in Taiwan. (TFB 1995)

1. Function

Crown closure map / competition map

The crown closure map and competition map could be intepretated from aerial photos or image processing of remote sensing. The desired future condition of crown closure map could be derived by model. Thinning operation could be designed in screen. Feng & Lee (2000) made the tree location map of 5 different density of permanent sampling plots (PSPs) in *Cryptomerria japonica* with the GIS approach. Then, tree crown closure maps were made to investigate the gap change in different ages. The parameters of Schnute's individual tree growth models were used to explore the change of gap influence upon the tree growth. The results showed that the wider the gap, the larger carrying capacity of the growth curve and parameters of the Schnute's model. The gap variable was suggested to put in the stand growth model and individual tree growth model for estimating efficiently.

Growing stock map and age distribution map

The patch distribution of class of growing stock and age class could be showed from plantation records and the results of forest inventory and analysis. We could develop the spatial growth model and growing stock estimation model of spatial explicit. The habitat factors could be integrated into model easily. We try to estimate the sink and flux of carbon sequestration from re-measure the 2800 permanent sampling plots (which classified by forest types and different elevation of 37 working circles) and the annual ring data of incremental boring cores.

2.Interpolation GIS were used to retrieve the data for developing spatial interpolation models and predict model.

The data got from permanent sampling plots (SPS), monitoring stations and observation stations were point data. We use point data of different temporal scale of historical records (such as annual average temperature, temperature for each month, radiation and precipitation etc.) to do area spatial interpolation with Kriging, tendency surface and alpine.GIS were used to interpolate and display the results of simulation with bio-ecological scenarios or/and social-economical scenarios in different spatial and temporal scales.

There are several studies were to do spatial interpolation of forest habitats and classification for forest ecosystem management and research in Taiwan area. The data were came from (a) Digital Elevation Model from a 40m*40m grid, (b) 26 climate stations (c) 818 rain stations (d) 1,791 sampling points for soil resources. (e) Permanent sampling plot. The 12 forest habitat variables were: elevation, slope, aspect, yearly mean temperature, mean maximum temperature (from July), mean low temperature (from January), total precipitation per year, total precipitation per winter season, total precipitation per summer season, and soil type, soil class, and effective depth. Interpolation methods were Kriging, trend method and Thiessen polygon. Finally, results showed mono-multinomial trend model was used to interpolate temperature, Kriging model to precipitation and soil effective depth, and Thiessen polygon method to soil class and soil class. Habitat classification was determined using multivariate cluster analysis of K-means. Habitat data used were collected from a Taiwan raster base-map of 35,990 grids that are 1km square. The 12 habitat variables of these grids were classified using cluster analysis K-means. A total of 948 habitat clusters were determined for Taiwan (R-square: 0.95).

Ecoregion / clustering and Holdriage life zoning /

Holdridge (1967) developed the eco-regions classification system with the relationship of climate variables of bio-temperature, annual precipitation, potential evapor-transpiration ratio, (PET Ratio) with main ecosystems of the earth. The Holdridge eco-region classification model were used to approach the vulnerability and adaptation assessment of the impacts of climate change on forest vegetation in Taiwan. To adapt the model we gathered meteorological data from 26 climate observation stations and 818 precipitation stations; in addition, land-use maps made from interpolating 32,720 aerial photos and 4,002 plots ground surveys 40m x 40m DEM are also used in our spatial analysis. Trend and Kringing spatial analysis modules of GIS are used to interpolate the grid-surface information from point data of precipitation and average temperature. The two primary parameters of Holdridge eco-region classification model are bio-temperature and annual average precipitation. Using this model, we then classify Taiwan Zone into Boreal (Subalpine), Cool Temperate (Mountain), Warm Temperate (Lower Mountain) and Subtropical (Premountain) and 10 sub-ecoregions. The forest types, species compositions of the 10 sub-ecoregions are got from overlapping the eco-region map and land-use map by using ArcView GIS.

Different thresholds could be set for developing multi-scale climate regions with cluster database. We set 3, 4, 7, 8, 12, 48 clusters as thresholds by the curve of Euclidean distance and group number. The group distributions of habitats with different thresholds were mapped. Habitat clusters and corresponding map variable data constructed a database for ecosystem study and management.

The habitat clusters in the Environments Database of Taiwan were reclassified into climatic regions by average linkage method. The results of the reclassification were used to compare with the climatic regions of Chen, Zheng-Xiang and Holdridge life zone classification model. The discrepancies of the climatic regions are due to zoning by regionalist and hierarchical classification method. The differences of the studied eco-region are due to diverse in classified factors.

Derived Habitat factors distribution / different temporal scale / different spatial scale

ESQ /HIS

The model could be used to evaluate the site quality of each interested species with their characteristics respond to habitat. There are 3 tree species which are *Chamecyparis frmosenisis, Taiwania Cryptomerioides and Acacica Confusa* were taken as examples in the SQ evaluation of plantation center area afforestation area. Finally, the actual distribution of natural forest types of interested species in 26 plantation centers and Huisun forest experimental station were validated. Most of them are located in the high SQ areas.

Applying site factors to evaluate site quality, we could evaluate site quality of many tree species at the same time and solve the spatial heterogeneity which empirical method could not achieved. Therefore, the assessment method can be applied in the selection of species for afforestation or species selection in forest restoration area. Collecting the attributes of planting species, spatial distribution data and environmental factors, we could integrate and analyze the data for further simulating the forest dynamics of forest in Taiwan. Evaluation of the impact of global change on forest also could be done.

3. Productivity ESQ

The totality of the effects of environmental (site) conditions on tree growth, also referred to throughout as totality of "environmental response functions" and denoted in the general form by f(environment) in equation is a product of several factors (Botkin, 1993): $\boldsymbol{f}\textbf{(environment)}=\boldsymbol{f}_{\mathbf{i}}\textbf{(AL)}\times \boldsymbol{Q}_{\boldsymbol{i}}\times\textbf{s(BAR)}$ **….(1)**

For a tree of the *i*th species, where f_{i}(AL) is the light response of the species

s(BAR) is a function of the maximum basal area that that plot can support.

Q_i is referred to as the site quality

The parameters of tree species respond to environments are showed in table 1. The 3 tree species are Red Cypress*(Chamascyparis formosensis),* Taiwania*(Taiwania cryptomorides),* Acacia*(Acacia confusa).*

Table 1. The suitable site factors of ecological site quality (ESQ) of 3 tree species.

Attribute / Species Tree	Shade intolerant or tolerant tree	Average of degree-days: γ	Standard deviation of degree-days: σ	$WLMAX_i$	Tolerance classes of available nitrogen in soil
Red Cypress *(Chamascyparis formosensis)*	Shade intolerant	2677.32	1092.76	0.53	Tolerant
Taiwania *(Taiwania cryptomorides)*	Shade intolerant	3160.42	1005.95	0.13	Intolerant
Acacia *(Acacia confusa)*	Shade intolerant	5716.64	698.97	0.53	Tolerant

Light is one factor of site factors, also affects the growth of trees. So we use equation (2) to evaluate site quality:$\boldsymbol{SQ_i = f_i(AL) \times TF_i \times WiF_i \times Nf_i}$……*(2)*

SQ_i is site quality index

f_i(AL) is the light response of the species.

$f_i(AL) =$ 2.24 (1–exp (–1.136 (*AL*–0.08))) , AL: relative radiation ….(3)

Tfi is the temperature function $TF_i = e^{\{-(DEGD-\gamma)^2/2\sigma^2\}}$ ….(4)

DEGD：degreeday (0C)）γ ：average of maximum temperature index σ ：standard deviation of temperature index---(5)

WiF$_i$ is the “wilt” factor $WiF_i = \max\left\{0_j, 1-\left(\frac{WILT}{WLMAX_i}\right)^2\right\}$ WiF_i : I isps responded to soil wilt,

$WLMAX_i$:isps respond to dry tolerate --(6)

$WILT = \frac{(E_0 - P_0)}{E_0}$ E0 :potential evaportrasportation P0: maximunm precipation

NF$_i$ is an index of tree response to nitrogen content of the soil.---- (7)

$\lambda_N = \alpha_1[1-10^{-\alpha_2(AVAILN+\alpha_3)}]$ (4)

λ_N ：N concentration of leaf in different tree(%)

λ_N *AVAILA*：amount of available nitrogen（Kg/ha）

NF_i ：N respond function of isps α_1 ~ α_6 ：coefficient

$$NF_i = \frac{(\alpha_4 + \alpha_5 \times \lambda_N)}{\alpha_6}$$

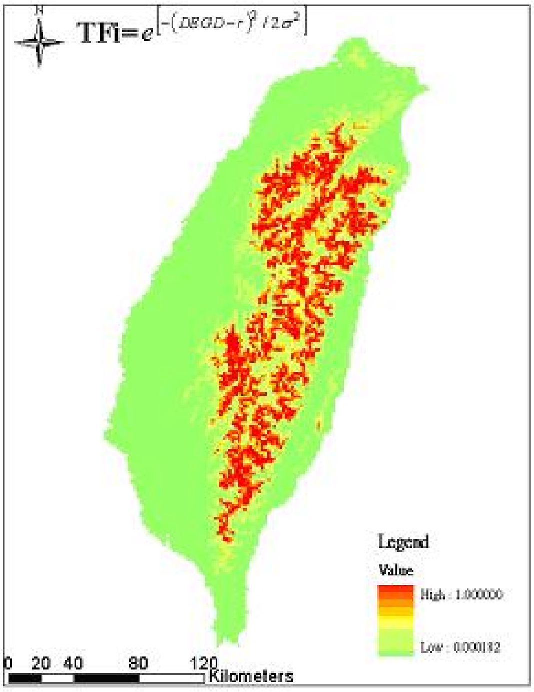


Fig 11. The thermal properties (TFi) distribution of *Chamaecyparis formosensis* in Taiwan.

Fig 12. The light response index (RFi) distribution of *Chamaecyparis formosensis* in Taiwan.

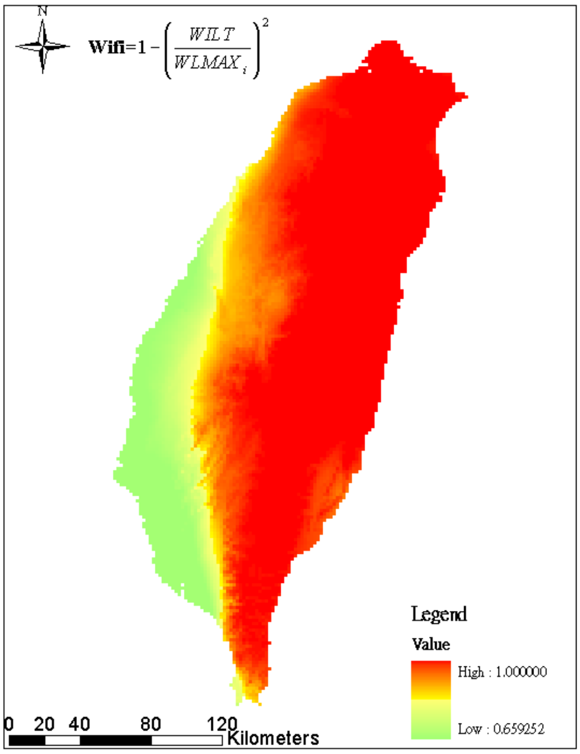


Fig 13. The soil drought factor (Wifi) distribution of *Chamaecyparis formosensis* in Taiwan.

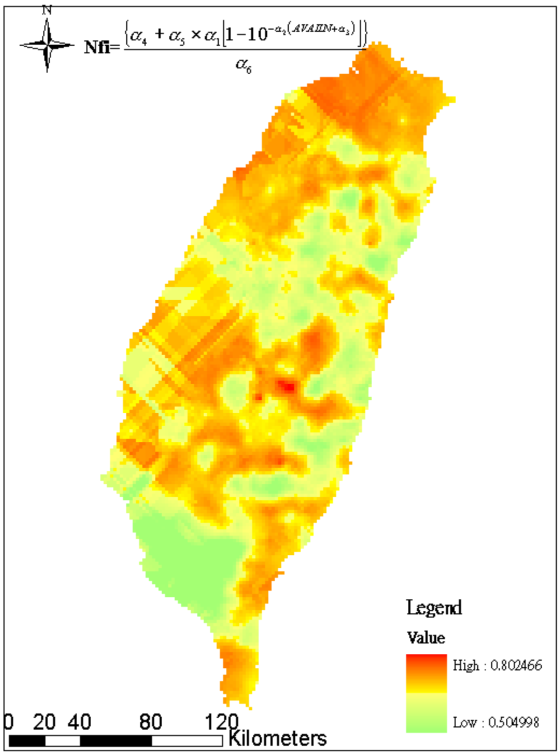
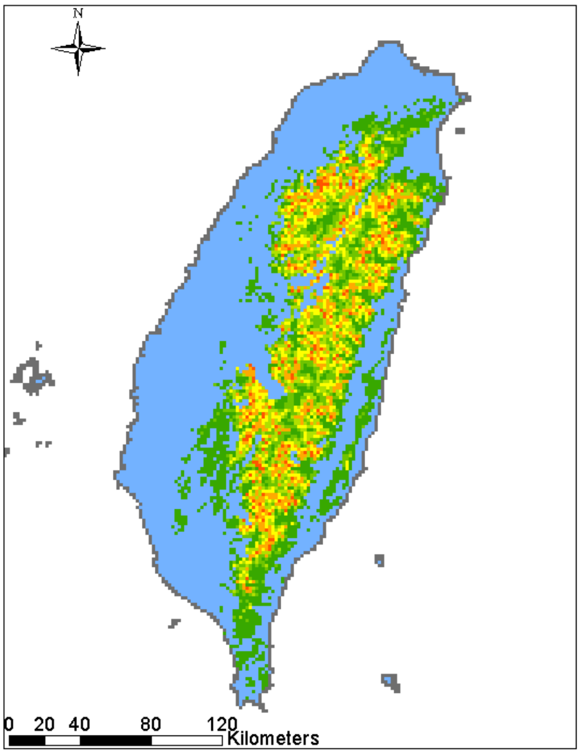
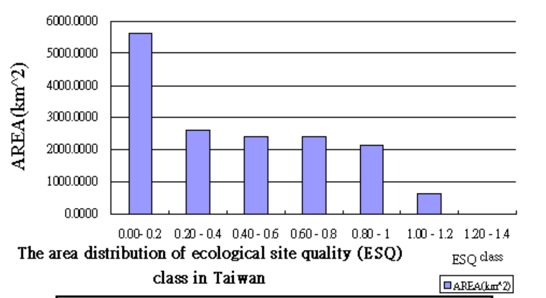


Fig 14. The Nitrogen factor (Nfi) distribution of *Chamaecyparis formosensis* in Taiwan.





The area distribution of ecological site quality class in Taiwan		
CLASS	COUNT*	AREA (km²)
0.00- 0.2	3518391	5629.4256
0.20 - 0.4	1629624	2607.3984
0.40 - 0.6	1501128	2401.8048
0.60 - 0.8	1518771	2430.0336
0.80 - 1	1330834	2129.3344
1.00 - 1.2	384809	615.6944
1.20 - 1.4	4	0.0064

note： *The number of 40m*40m grid

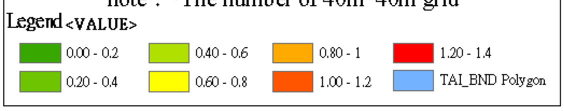


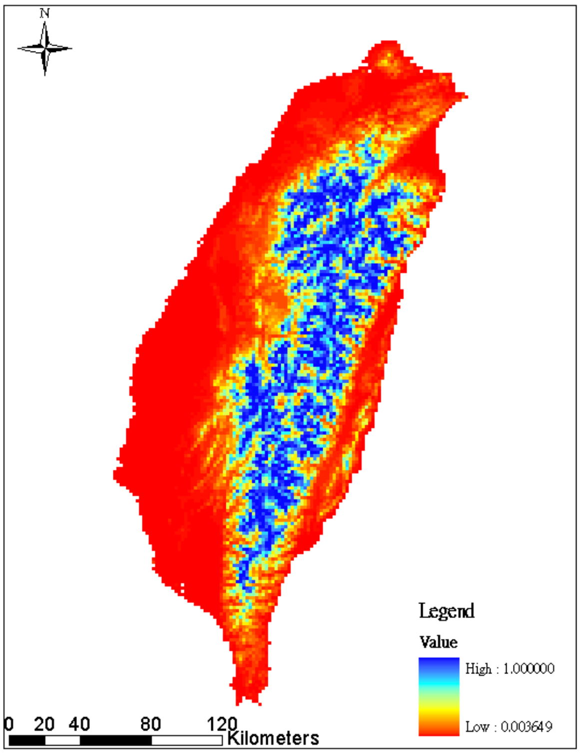
Fig 15. The ecological site quality index (ESQI) distribution of red cypress in Taiwan.

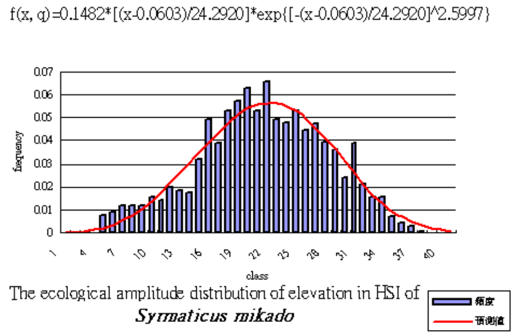
4. Landscape habitat diversity with HSI

The location of observed and surveyed recorded data of Mikado pheasant was selected to get the 12 forest habitat variables, which the key suitable index (SI) of Mikado pheasant.

The 12 forest habitat variables were: elevation, slope, aspect, yearly mean temperature, mean maximum temperature (from July), mean low temperature (from January), total precipitation per year, total precipitation per winter season, total precipitation per summer season, and soil type, soil class, and effective depth. Interpolation methods were Kriging, trend method and Thiessen polygon. Finally, results showed mono-multinomial trend model was used to interpolate temperature, Kriging model to precipitation and soil effective depth, and Thiessen polygon method to soil class and soil class. (Kao and Feng, 2001).

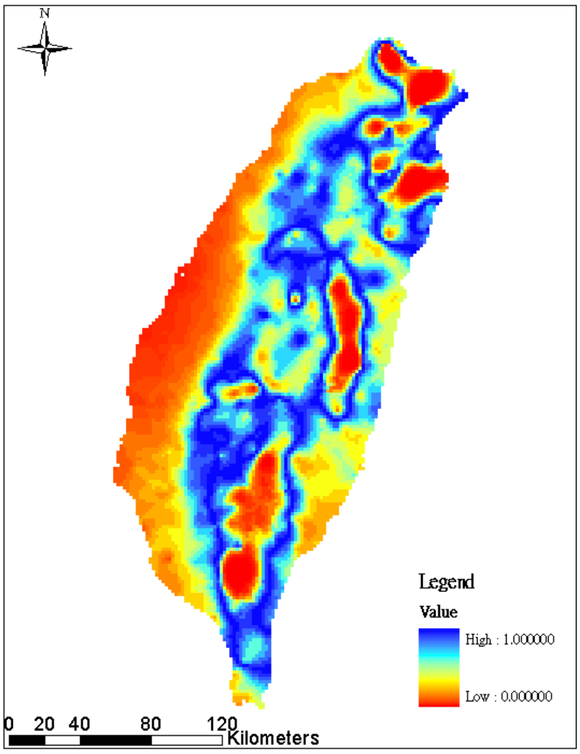
Elevation, yearly mean temperature and total precipitation per year were selected for HSI. Weibull pdf were used to normalize ecological amplitude of these three variables. The results showed that Weibull pdf do a good description of the distribution of ecological amplitude (under the range of 1~0) with K-S goodness of fit test. All the K-S goodness of fit are $D_n < D_{0.01}$ and $D_n < D_{0.05}$. We accept the ecological amplitude distribution and Weibull pdf share the same distribution, which showed Weibull could describe the ecological amplitude distribution of “elevation”, “total rainfall per year” and “mean temperature per year” very well. The parameters of Weibull which describe the ecological amplitude distribution are elevation (A: 0.0603, B: 24.2920, C: 3.5997), total rain per year (A: 0.2526, B:29.0365, C: 6.0999), mean temperature per year (A: 0.1588, B:19.0383, C: 6.0000). The theoretical frequency value of each grid could be estimated, the distribution of these 3 normalized ecological amplitude are showed in Fig 16, Fig 17 and Fig 18. We multiplied these three indexes to get the HSI of each grid as Fig 19. The area of each HIS classes could be easily calculated and located where they are.

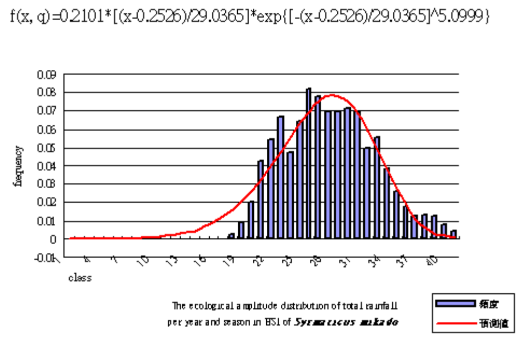




elevation			
parameters	value	critical value	value
A estimator	0.060300	$D_{0.05}$	0.0541
B estimator	24.292000	$D_{0.01}$	0.0649
C estimator	3.599700	D_n	0.0220
number(	1260	Ho test	accept

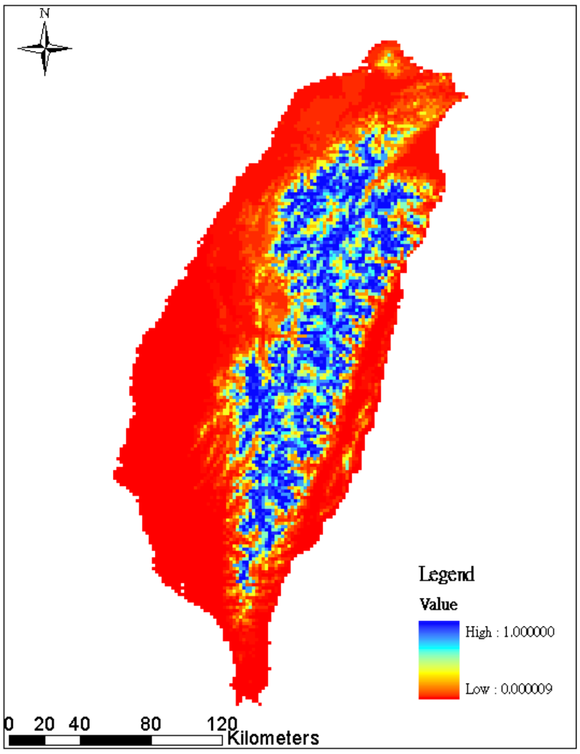
Fig 16. The ecological amplitude distribution of elevation in HSI of *Symaticus Mikado*.

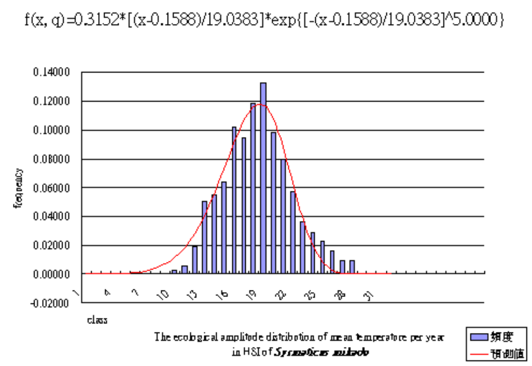




Total rainfall per year and season			
parameters	value	ritical valu	value
A estimator	0.252600	$D_{0.05}$	0.0541
B estimator	29.036500	$D_{0.01}$	0.0648
C estimator	6.099900	D_n	0.0730
number(	1260	Ho test	not accept

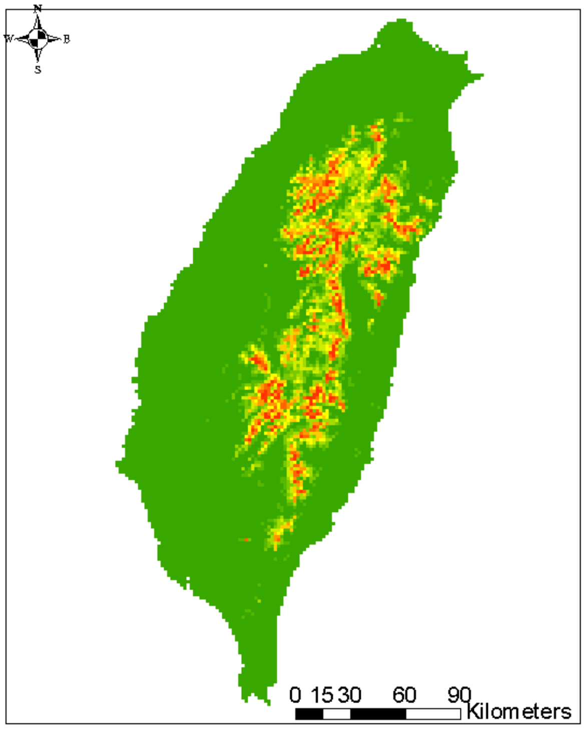
Fig 17. The ecological amplitude distribution of total rainfall per year and season in HSI of *Symaticus Mikado*.

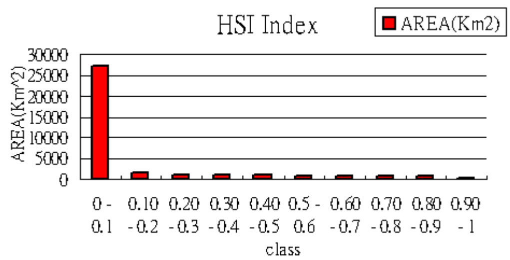




Mean temperation per year			
parameters	value	ritical valu	value
A estimator	0.158800	$D_{0.05}$	0.0541
B estimator	19.038300	$D_{0.01}$	0.0648
C estimator	6.000000	D_n	0.0538
number(	1260	Ho test	accept

Fig 18. The ecological amplitude distribution of mean temperature per year in HSI of *Symaticus Mikado*.





CLASS	COUNT	AREA(Km^2)
0 - 0.1	17034868	27255.789
0.10 - 0.2	1065360	1704.576
0.20 - 0.3	835360	1336.576
0.30 - 0.4	741971	1187.154
0.40 - 0.5	664906	1063.850
0.500 - 0.6	526988	843.181
0.60 - 0.7	493987	790.379
0.70 - 0.8	420153	672.245
0.80 - 0.9	415420	664.672
0.90 - 1	300812	481.299

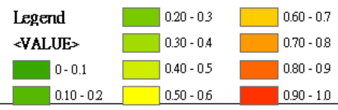


Fig 19. The potential distribution area of *Symaticus Mikado* in Taiwan by HSI.

In the study, we used guild concept to modify a single species HSI model to a multiple species HSI models. The multiple species model incorporated with forest structural factors enhanced the power of predicting the distribution of a species. The model could be used to simulate forest-thinning scenario in Taiwan. The impact of the forest management scenario on guild was demonstrated. The model could be widely applied on simulating the impacts of various forest management strategies on an avian community.

2. Change

Stand growth modeling with Schnute’s and Richards’ model/ Stand treatment

The Schnute's growth model is applied to the different characteristics of stand growth, stand structure of 5 kinds of density of *Cryptomeria japonica* man-made forests in Taiwan. Excellent agreement between observed and expected values has been obtained. From the fitted parameters of different density, site quality, growth period, and different stand characters, we can clearly see that Schnute's growth model can successfully tracked sigmoid growth, reversed J-form and renewed growth.

The parameters of Schnute's growth curves can response to the different densities of stand. To sum up the study of 5 kinds of density of Cryptomeria japonica plantation in Taiwan, the parameters obtained can be divided into 3 growth types. The different growth types of diameter of breast height are described as follows: (1) when the stand density is under 1000 stems per hectare, the parameters of the general growth model is $0<r$ and $0<s<1$, and the growth curve is sigmoid; (2) when the stand density is 1,000-3,500 stems per hectare, the parameters of the general growth model is $0<r$ and $1\leq s$, and the growth curve is reversed J-form with asympototic line and non-inflection point; (3) when the stand density is more than 3,500 stems per hectare, the parameters of the general growth model is $-s\cdot\ln(W_2/W_1)/(T_2-T_1) <r\leq 0$ and $1<s$, and the growth curve is beyond the asymptotic level; with two asymptotes in sigmoid shape.

Scenario of climate change / Patch dynamic

.Feng and Kao (2001) simulated the environmental changes using Holdridge eco-region classification model of Taiwan as doubly increasing CO2 concentration and incrementing from 1℃, 2℃ and 4℃ scenarios. The vegetation communities will be changed; the zones of sub-mountain rainforest and sloped-land dried forest would be disappeared. Humid rainforest is occupied large area (32.3980%)，The area of tropical humid forest will increase to 36.99%.

The tool of GIS is very useful in spatial interpolation, overlapping different map-layers and scenarios. Taiwan Eco-regions by Holdridge Vegetation-Climate Classification Model under the scenario of increasing 1℃, 2℃ with 2 fold CO2 concentration

Table 2. The Area of Holdridge Ecoregions by 3 different Scenarios of Increasing Temperature of 1℃, 2℃, 4℃ (unit: ha ,%).

Holdridge Eco-region	Baseline (ha)	比例	Temp. Increase 1℃ (ha)	Percentage	Temp. Increase 2℃ (ha)	Percentage	Temp. Increase 4℃ (ha)	Percentage
北方地帶(亞高山)雨林	5,500	0.1528%	3,000	0.0834%	500	0.0139%	0	0.0000%
冷溫帶(山區)雨林	218,300	6.0656%	152,500	4.2373%	96,900	2.6924%	26,300	0.7308%
冷溫帶(山區)潮濕森林	82,800	2.3006%	102,500	2.8480%	82,800	2.3006%	32,500	0.9030%
副熱帶(山坡地)雨林	174,600	4.8514%	109,300	3.0370%	85,300	2.3701%	49,300	1.3698%
副熱帶(山坡地)乾燥森林	160,000	4.4457%	206,900	5.7488%	22,900	0.6363%	0	0.0000%
副熱帶(山坡地)潮濕森林	1,463,488	40.6639%	1,440,188	40.0165%	1,395,388	38.7717%	1,166,000	32.3980%
副熱帶(山坡地)濕潤森林	1,367,600	37.9996%	1,216,400	33.7984%	927,500	25.7711%	420,000	11.6699%
熱帶乾燥森林	300	0.0083%	10,200	0.2834%	252,000	7.0020%	403,000	11.1976%
熱帶潮濕森林	4,800	0.1334%	9,900	0.2751%	34,800	0.9669%	170,700	4.7430%
熱帶濕潤森林	121,600	3.3787%	348,100	9.6722%	700,900	19.4749%	1,331,188	36.9878%
合計	3,598,988	100.0000%	3,598,988	100.0000%	3,598,988	100.0000%	3,598,988	100.0000%

3. Forest Ecosystem Management

1. To set the objections of EM.
2. To develop the criteria and indices (C&I) of sustainability in EM of country.
3. To collect the data under the C&I selected in different working circles (management units)
4. To build the geo-referenced DBMS of ecosystem management in Taiwan.
5. To integrate the information of Taiwan’s forest resources management, the landscape ecological classification system and practice in Taiwan in Geo DBMS.
6. To develop the national forest ecological classification system, and decide more suitable ecological units by using the data of geo-referenced DBMS.
7. Developing the criteria and indicator (C&I) of sustainability in each eco-regions level and local level from bio-ecological and social-economical viewpoints.

8. To estimate the information of status, function and change for C&I and planning by developing monitoring system
9. To develop the strategic, tactical and operational plan of ecosystem management under the ecological classification system of landscape level in whole island level and watershed levels.
10. From developing the investigating and monitoring system, we could collect and integrate the data of l forest management in geo-referenced DBMS for adaptive management.

We could set the flow-chart as follows:

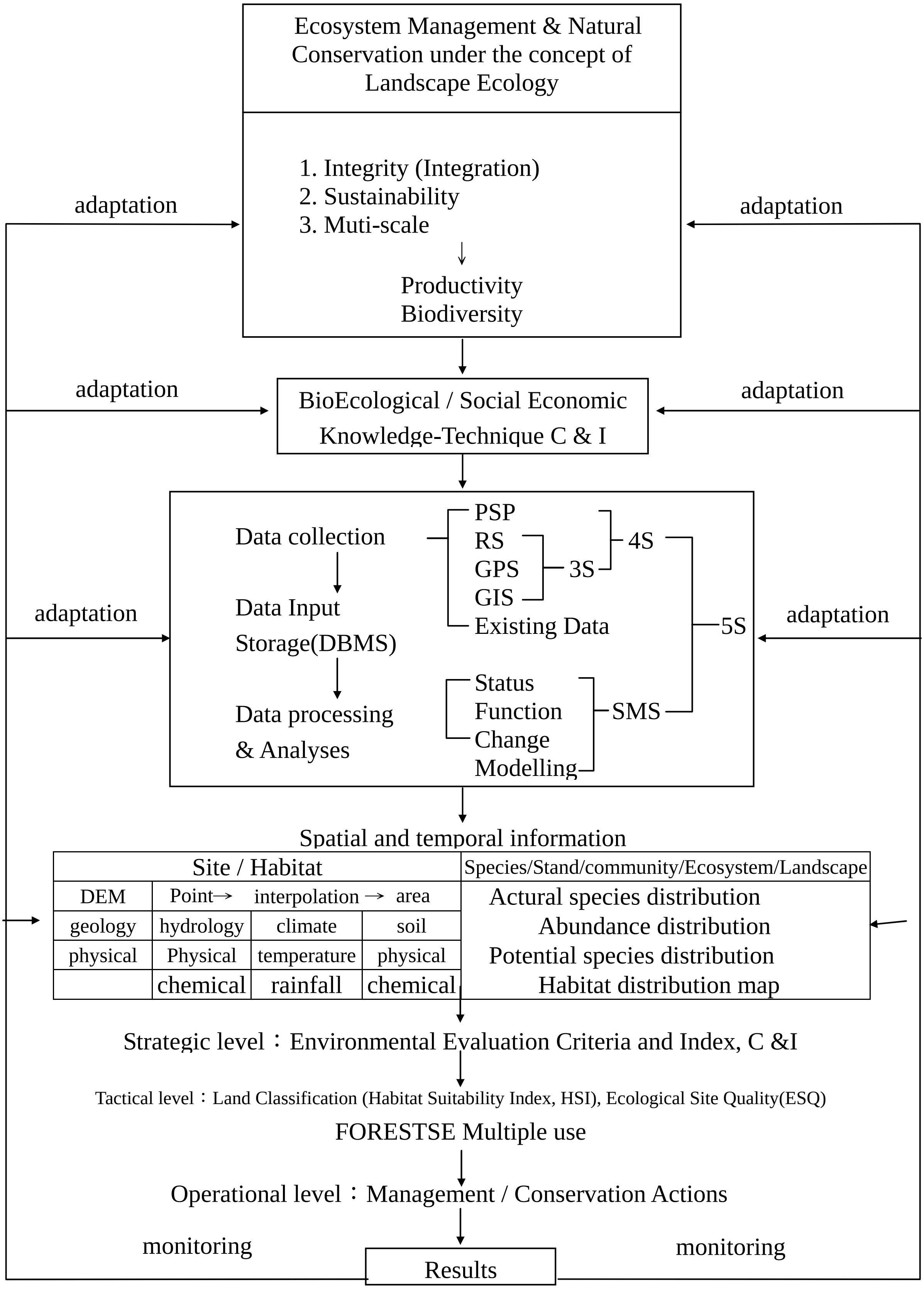


Fig 1. The scheme of 5S application to ecosystem management.

4. **Criteria and Index (C&I) / Monitoring system**

We have to set up the criteria and index of sustainability in country and different levels of eco-regions, when implementing ecosystem management (EM).

No matter what forest resource conservation assessment, strategy planning, implementation, management, monitoring and adaptive strategy, it is very important to define the criteria and indicators(C&I) of ecosystem management (EM). Feng and Kao (2001) and Feng & Lee (2003) established the criteria and indicators of sustainable forest with stress-pressure-response (SPR) by questionnaires for Taiwan. Referring to the condition of now-a-day society, economics, and culture, we try to propose the C&I of EM in Taiwan. The C&I of EM presented are based on biological, ecological, social and economical viewpoints under the environmental condition and the demand of people. Those C&I could apply to make the policy, plan, purpose, and target of Taiwan forest management. Applying the C & I, we could set up the policy, planning, assessment and monitoring forest management in Taiwan.

To scale-up the information of different scales.

The forest variables and habitat factors of surveyed sampling plots were used to develop the model of "ecological site quality index (ESQI)". We use the ESQI to estimate the land productivity of each ecological unit and patch of landscape. The species and abundance of surveyed animals were integrated with habitat variables of different levels to develop the "habitat suitability index (HSI)" of some species or guild.

Species spatial distribution, species abundance and habitat suitable index are important information for wildlife management and conserving biodiversity. Therefore, the techniques for evaluating wildlife habitats quantitatively are important tools for Ecosystem Management (EM). We integrated the digital photogrammetry and geographic information system(GIS) technology to present the land-use pattern, digital surface model (DSM), stand closure patterns of a forest ecosystem. GIS database with ground surveyed data of species and forest stand characteristic information were used to generalize the habitat characteristics of wildlife community in Hwei-Sum forest ecosystem located in the center of Taiwan. Habitat Suitable Index model (HSI) was used to simulate the changes of an avian guild by following a typical forest management scenario. Spatial analysis with GIS technology can provide valuable insight of developing the potential distribution map for an avian community. The technique can be a valuable access for setting up a feasible wildlife management policy.

5. To build up the monitoring system of ecosystem management with 5S technique

The habitat suitability index (HSI) could be used to estimate the potential area of interested species or guild under the criteria of "biological diversity". In the paper, the habitat suitability of Mikado pheasant (*Syrmaticus Mikado*) was evaluated with HSI. Two of them are endogenous species in Taiwan. There are 3 species of pheasants in Taiwan. We evaluated the potential suitable habitats of peasants in Taiwan.

6. To integrate GIS and landscape ecology in designing the desired future condition

The desirable future condition (DFC) of stable forest landscape could be develop by the succession model with Semi-Markov chain which consider the delay holding time of each components of the landscape. Cellular Automate technique also, could be used to map the location of patches each kind of component of landscape.

7. To do adaptive management in forest ecosystem management with experimental design.

CONCLUSION

To evaluate habitat suitability of wildlife and productivity of specific species and community, forest types are the main works of ecosystem management. Evaluating the effectiveness of permanent sampling plots, protected areas, and LTER also could be evaluated with GIS, DBMS and spatial modeling.

The resource techniques of GIS, GPS, RS, PSP and developing simulation model system (SMS) are supplied spatial and temporal information for forest ecosystem management. The function of accumulation and integration, make GIS do a wonderful job in ecosystem.

The base maps of ecosystem management in Taiwan are working circles compartment map in vector format 40m x 40m grid and 1kmx1km grid in raster format, separately.

In the study, the situation maps and potential distribution maps were used to explain the application of spatial information in ecosystem management. Situation maps of index under the criteria of “extent of forest resources”, “productive functions of forests”; “biological diversity” and “protective functions of forest” in Taiwan were showed with forest types, species composition, stand structure and growing stock were showed in the distribution map.

These four forestland zones are nature reserves, land protection area, forest recreation area and timber management area, which could be classified easily by working circles and compartment maps.

The spatial information could show the index of forest sustainability in different scale such as whole national scale and working circle scale.

The potential productivity of timber were estimated with ecological site quality (ESQ) index in *Chamaecyparis formosensis* under the criteria of “productive functions of forests” and get a good results by checking with natural distribution of red cypress. There are ecological variables of topology, climate and soil in the ecological site quality (ESQ) index.

The habitat suitability index (HSI) could be used to estimate the potential area of interested species or guild under the criteria of “biological diversity”.

RS, GPS, and PSP were used to get spatial data of ecosystem management. GIS could be a wonderful tool for Forest Ecosystem Management multi-scale geo-referenced DBMS is the core of spatial data management. Objective setting, criteria and index development, data collection data integration, eco-region classifications, site selection are the core issues for ecological processing research. PSP designed for monitoring system. Scenario simulation could be used for planning, DFC setting, evaluation site quality of land and the sustainability of EM.

In the study, temporal-spatial informatics was applied in Forest ecosystem management (EM) in Taiwan as follows:

(1) To develop the forest ecosystem multi-scale Geo-DBMS of Taiwan in biology and habitat.
(2) 5S (RS, GPS, PSP, GIS and SMS) techniques were used to data collection storage and analysis
(3) GIS were used to retrieve the data for developing spatial interpolation models and predict model.
(4) Apply the GISs and modeling for eco-region classification.
(5) To set up the criteria and index of sustainability in different levels and eco-regions.
(6) GIS were used to interpolate and display the results of simulation with bio-ecological scenarios or/and social-economical scenarios in different spatial and temporal scales.
(7) To scale-up the information of different scales.
(8) To build up the monitoring system of ecosystem management with 5S technique
(9) To integrate GIS and landscape ecology in designing the desired future condition
(10) To do adaptive management in forest ecosystem management with experimental design.

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Appendix